Multiplex Telegraph

Electrical Experiments

by A. G. B.

Vol. III

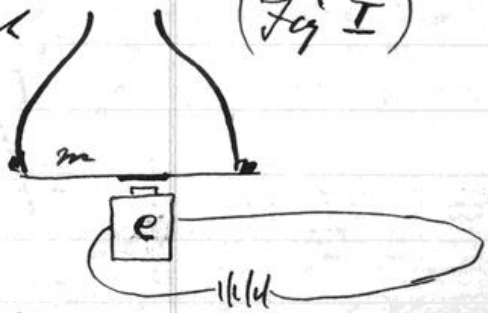
Hooper, Lewis & Co., Manufacturing Stationers, 122 State Street, Boston.

Sunday

October 1st 1876

The problem before us in utilizing the undulatory current is evidently how to obtain the maximum of inductive action with the minimum of vibratory motion.

In order to do this satisfactorily it seems to me to be necessary to understand the nature of the effect produced upon the current. Does the vibration of m (Fig I) occasion an inductive action of its own which is merely superposed upon the current traversing e — or is the effect proportional to the magnetical power of e ?



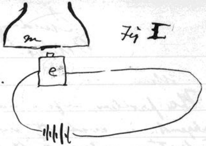
(Fig I)

Experiments so far seem to indicate that the latter supposition is correct. The power of the electro-magnet (e) however depends upon the electro-motive force of the battery and upon the ~~resistance~~ resistance of the electro-magnet relatively to the rest of the circuit.

When the electro-motive power of the battery is kept ~~constant — variations~~ constant variations in the intensity of the current may be considered — without error — as due to corresponding changes in the resistance of the circuit.

The effect then of the vibration of m is supposed to depend upon the magnetical power of the electro-magnet (e); and the power of the electro-magnet depends upon the resistance of its coils relatively to the rest of the circuit, and upon the electro-motive force of the battery.

The electromotive force (E) of the battery ~~and the normal rest is supposed~~ is constant — and ~~the effect of~~ the vibration of m is considered as causing a variation in (R) the resistance of ~~the electro-magnet (e) expresses the total resistance of the circuit in terms of R — say x R~~ (e) expresses the resistance of the circuit in terms of R.



E = Electro-motive force of battery.

R = Minimum resistance of e.

AR ~~[illegible]~~ = maximum resistance of e.

BR ~~[illegible]~~ = Total ~~[illegible]~~ resistance of the circuit exclusive of e.

I = Maximum intensity of current

i = minimum intensity of current.

~~$I = \frac{E}{R(y+1)}$, $i = \frac{E}{R(x+y)}$; $\frac{I}{i} = \frac{x+y}{y+1}$~~

$$\left.\begin{aligned} I &= \frac{E}{R(B+1)} \\ i &= \frac{E}{R(A+B)} \end{aligned}\right\} \therefore \frac{I}{i} = \frac{A+B}{B+1}$$

~~Hence it is evident that~~ The difference between I and i will be at its maximum when B is at its minimum and vice versa. Hence the greater the resistance of e (Fig I) ~~as~~ relatively to the resistance of the circuit the greater will the amplitude of the electrical undulations be. But as the absolute intensity of the current is equivalent to the electro-motive force divided by the resistance of the circuit — the greater the resistance of e the less the absolute intensity of the current and the less the magnetic power of e. It is evident then that for a given circuit a certain resistance of e can be found which will yield the maximum effect.

Noted Oct. 10th by A.G.B.
Copied Oct. 14th 1876
by AGB

Monday Oct. 2d 1876

Upon reading over a few of the records in the 2d volume of my electrical experiments — I was struck by an experiment made July 11th (page 27) which I had quite forgotten. Why we have relinquished the improved form of armature shown in Fig I page 27 (2d vol.) — I cannot think. Shall repeat this experiment.

It will be a good plan to repeat all the earlier experiments — with the improved receivers we now have.

Noted Oct. 14th 1876
by A.G.B.

Oct. 2d — to Oct — 7th 1876

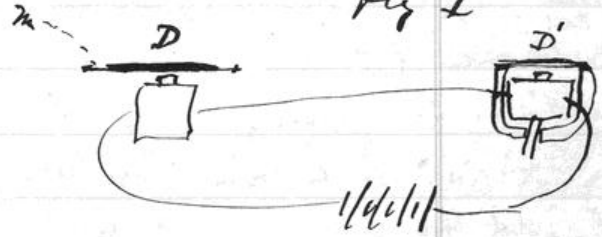
No experiments have been irregularly conducted during this week — and have not been noted in consequence of omission to procure a new book. We are convinced of the very great importance of noting every experiment at the time it is made — as the remembrance so soon fades away. A number of experiments made during the last few days have been forgotten.

Experiment referred to above (Monday Oct 2d) was tried during the week. The large armature was found to be infinitely superior to the small one employed.

A large disk of thin steel was glued to the membrane M and Mr Watson spoke with his mouth almost in contact with D condensing his breath by means of his hands.

I listened at D'.

Fig I



The articulation was much more distinct than any heard yet. I then spoke with my mouth against D' and Mr Watson listened at D and the articulation was intelligible. We then held the following conversation.

The following conversation took place.
I think this was on Saturday the 7th of October.

1st Bell to Watson. "If you understand what I say say something to me.

Watson to Bell (as heard by me.) "It is (decidedly) the best I ever heard"

Bell to Watson. "It is the best I ever heard."

Watson to Bell. "Success at last has (attended) our efforts."

Bell to Watson "Let us then be up and doing
With a heart for any fate.
Still achieving still pursuing
Learn to labour and to wait"

Noted by A. G. B.
Oct. 10th 1876

Monday Oct. 9th 1876

Fig I

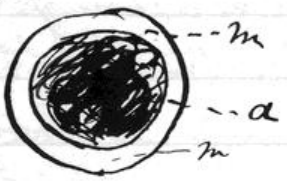
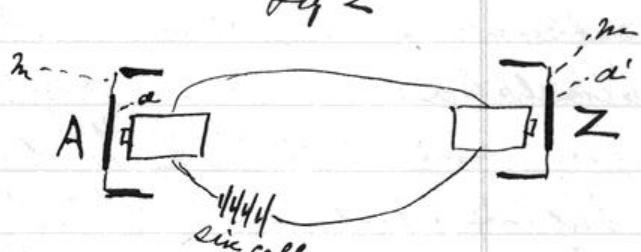


Fig 2



Two telephones shown at A and Z Fig 2 were ready for trial today. The armatures a a' (Fig 2) like that shown at a (Fig I) were glued to membranes m m' (Fig 2) as illustrated in Fig I.

I spoke with my mouth close to A condensing the air upon the membrane with my head while Mr Watson listened at Z. Then Mr. Watson spoke against Z and I listened at A. The articulation was so distinct and clear that we were enabled to hold the following conversation through the wire which was recorded by each of us at the time. The two records were as follows:—

Conversation as recorded by A G Bell. stationed at one instrument

Bell. If we can manage to understand each other on this short circuit I think we may try a real telegraph wire.

Watson. It seems to me that the articulation is almost distinct enough for practical use

B. I understand every word you say, but I think the

Conversation as recorded by T. A. Watson stationed at the other

Bell. If we can manage to understand one another on this short circuit I think we can try a real telegraph line

Watson. It seems to me that the articulation is almost distinct enough for practical use

B. I understood every word you said, but I think that the

armature of your telephone must be loose as a curious hollow sound accompanies the articulation

W. The armature is loose at the edges but I do not think that that is the cause of the hollow sound

B. It seems to me that the articulation is much distinct when I do not press my ear closely against the membrane

W. I understand you better when you speak conversationally rather than so deliberately

armature of your telephone must be loose as a curious hollow sound accompanies the articulation

W. My armature is loose at the edges, but I do not think that that is the cause of the hollow sound.

B. It seems to me that the articulation is much distinct when I do not place my ear closely against the membrane.

W. I understand you better when you speak conversationally rather than so deliberately

At this point the experiment was interrupted by the arrival of a friend After some delay the conversation was resumed.

Recorded by W. Bell

B. A gentleman has just come in to see me. Do you know his name?

W. Please repeat that

B. A gentleman has just come in to see me, Do you know his name?

Recorded by W. Watson.

B. A gentleman has just come in to see me — — — —

W. Please repeat that.

B. A gentleman has just come in to see me Do you know his name?

W. I do not know his name. Is he interested in telephony?

B. He is interested, but neither pecuniarily nor professionally Can you receive a message from him? See if you can understand his voice

W. Repeat last word

B. Voice, voice V-O-i-C-E voice. See if you can understand his voice

W. Request him to talk to me.

Mr. Mack I fear it will be difficult to understand me, My voice is not so distinct as Mr. Bell's.

W. (as understood by Mr. Mack) Most intensely distinct but not

W. (as understood by Mr. Bell) Yes it was quite distinct but somewhat fainter

Mr. Mack. Please repeat what you said to me.

W. (as understood by Mr. Mack) It was distinct but somewhat fainter.

W. (as understood by Bell) Yes, it was quite distinct but somewhat fainter.

W. I do not know his name. Is he interested in telephony.

B. He says he is interested but neither pecuniarily nor (accessorily?)

Same voice as before Please repeat what you said to me.

W. That was quite distinct but somewhat fainter.

B. I want to tele you this gentlemans name

W. Please introduce him to me through the wire

B. Wait a minute

W. I am waiting

B. Allow me to introduce my frien. Mr. Mack of Belmont Massachusetts

W. (as understood by Mr. Bele) Mr. Mack, I am glad to make your acquintance

W. (as understood by Mr. Mack) Mr. Mack I am glad to make your acquintance

(The final sheet from which this is copied is missing, there have are two sentences mine.

Mr. Bele's wife I want to tele you this gentlemans name.

W. Please introduce him to me through the wire.

B. Wait a minute

W. I am waiting

B. Allow me to introduce my frien Mr. Mack of Belmont Massachusetts.

W. Mr. Mack I am glad to make your acquintance.

On the evening of the same day the Walworth Manufacturing Company lent Mr. Bele the use of their telegraph line extending from their office in Bolton to their factory in Cambridgeport - a distance of - about two (2) miles - The Company battery consisting of 9 Daniels cells was disconnected from the circuit and another of ten carbon elements substituted - Articulate conversation was then carried on through the wire. The sounds at first faint and indistinct became suddenly quite loud and intelligible - Mr. Bele in Bolton & Mr. Walton

in Cambridge Pat took notes at the time of what was said and heard & of which the following are copies.

Conversation as Recorded by Mr. Bell.

B. What do you think was the matter with the instruments?

W. There was nothing the matter with them.

B. I think we were both speaking at the same time

W. Can you understand anything I say?

B. Yes I understand everything you say

W. The reason why you did not hear at first was because there was a relay in the circuit

B. You may be right but I found the magnet of my telephone touching the membrane.

W. I cut the relay out & then the sounds came perfectly.

B. I hear every syllable, try something in an ordinary conversational voice

W. Shall I connect their battery in the circuit?

B. No, there is no necessity to

Conversation as recorded by Mr. Watson - -

B. What do you think is the matter with the instruments?

W. There is nothing the matter with them

B. I think - - - - - - - at the same time

W. Can you understand anything I say?

B. Yes I understand everything you say.

W. The reason why it did not work at first was because there was a relay in the circuit

B. You may be right, but I find - - - - that my - - - touches the membrane

W. I cut the relay out & then the sounds came out perfectly.

B. I hear every syllable, try something in a conversational voice

W. Shall I connect their battery in the circuit.

B. No there is no necessity for

connect their battery in the circuit the sounds come out quite loudly.

W. I am now talking in - quite a low tone of voice.

B. The sounds are quite as loud as before and twice as distinct

W. Cut out the battery and then talk.

B. All right, I will cut out the battery now if you will keep listening

B. I thought you were going to ~~say~~ say something

W. Is the battery cut out?

B. No, but I will do it now

B. Do you hear anything now.

B.- Did you hear anything?

W. No not a sound.

B. Say something to me when I cut out the battery again

putting their battery in the circuit as the sounds come out quite loudly.

W. I am now talking in quite a low tone of voice

B. The sounds are quite as loud & ~~quite~~ as distinct.

W. Cut out the battery and then talk.

B. All right I will cut out the battery now if you will keep listening

B. I thought you were going to say something.

W. Is the battery cut out?

B No, but I will do it now.

B Did you hear anything

W. No, not a sound

B. Say something to me when I cut out the battery ~~again~~ again.

B. I fancy I heard a trace of your voice.
W. Shall I put on their battery to see if it increases the effect?
B. Ile tele you what neill do Neill take off our battery & put on theirs as before.

W. Is our battery off?
B. Yes our battery is off. What have you been doing The sounds were quite soft at first but now they are quite loud.
B. Shall I put on our battery again?
W. (Very indistinctly) That was very indistinct put on our battery.
B. We may congratulate ourselves upon a great success
W. Both batteries are on now
(Another sentence heard indistinctly)
B. Repeat the last sentence
W. Both batteries are on now
B. I understood that before

W. I could not hear a sound
B. With the battery cut out
B. I fancied I heard a trace of your voice.
W. Shall I put on their battery to see if it increases the effect
2
B. Ile tele you what neill do Nele take off our battery altogether & put on theirs as before.

W. Is our battery off?
B (Very indistinct)

W. That was very indistinct - put on our battery
B. We may congratulate ourselves on our great success
W. We deserve success. Both batteries are on now.
B. Repeat last sentence.
W. Both batteries are on now
B. I understood that before

but I thought you said something else.

W. Remove their battery, please

B. All right our battery is the only one on now.

W. I have put battery cells on here

B. How many cells have you there

W. I— i— x.

B. Please whisper something to me.

B. I could hear you whispering but could not understand what you said

W. Perhaps we have got the batteries opposed to one another. Had you not better reverse your battery & see what the matter is—or rather what the effect is?

B. I will try the effect of reversing my battery.

B. Is this any better

W. That sentence was accompanied by a curious crackling sound.

B. Yes I hear it too—

but I thought you said something else.

W. Reverse your battery, please

B. All right our battery is the only one on now

W. I have six Daniels Cells on here

B. How many cells have you there

W. I— i— x six.

B. Please whisper something to me

W. I am now whispering

B. I could hear you whispering but could not understand what you said

W. Perhaps we have got the batteries opposed to one another Had you not better reverse yours and see what the effect is?

B. I will try the effect of reversing my battery

B. Is this any better?

W. Much fainter accompanied by that curious bubbling sound

B. What time is it by your watch?

W. What are you doing I have not heard anything except — — — for quite a while

B. I asked you what time it was by your watch perhaps you hear me better now because I have reversed the battery again

W. My battery is now cut out

B. Dont you think we better go home now?

W. Yes — but why does your talk come out so much fainter now?

B. Because I had moved the magnet further away from the membrane.

W. That was very much more distinct

B. Will you try to understand a long sentence if I speak right on?

W. I will

B. A few minutes ago I heard a fire engine pass by the door. I dont know where

W. What are you doing I have not heard anything except that bubbling sound for quite a while

B. I asked you — — — — — — — — — — because I — — — —

W. My battery is now cut out.

B. Do you think we had better go home now?

W. Yes — but why does your talk come out so much fainter now?

B. Because I removed the magnet further away from the membrane.

W. That was very much more distinct

B. Will you try to understand a longer question if I speak right on

W. I will

B. A few minutes ago I heard a fire engine go past the door I dont know where

the fire is but the number of the box is 196.

B. The time by my watch is five minutes past ten Lad I better not go into Boston.

B. Yes I think it time to stop now.

B. Shall I go to Exeter Place

B. Yes, but look in here in case I have not gone.

B. Let us talk conversationally without noising

the fire is, but the number of the box is 196.

B. The time by my watch is five minutes past ten Lad I better not go into Boston.

B. Yes, I think it is time to stop now.

B. Shall I go to Exeter Place

B. Yes but look in here on your way in case I have not gone

B Let us talk conversationally without noising.

Copied from notes by M.G.H. Oct 16 1876.

Wednesday Oct. 11th 1876

Communicated the results of Monday's experiments to the Academy of Arts & Sciences. At the conclusion of the meeting the members tested apparatus with good results. All were convinced. [illegible]

Upon the motion of the Hon. Geo. B. Emerson the congratulations of the Academy were tendered to me upon my success.

Noted Oct. 19th G

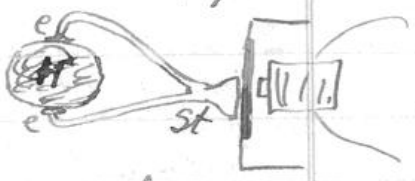
A.G.B.

Thursday Oct. 12th 1876

Dr. Bowditch called upon me to try the effect of using a double stethoscope as a means of increasing the audibility of the sounds. The sounds were undoubtedly louder when receiving as in Fig I.

Fig I

H head of listener
St Stethoscope
e.e. Ear pieces.



Noted Nov. 12th 1876

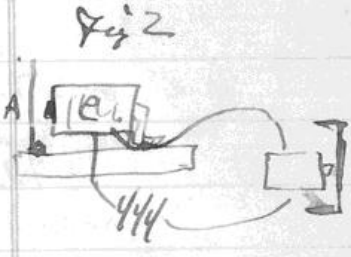
Thursday Oct. 12th to Sunday Nov. 12th

Systematic notation of experiments during this month has been almost impossible on account of many circumstances especially because I have been out of town ~~a two~~ in the evenings at Cambridge and at Bradford — and have been professionally engaged during the day. W. Watson's absence in Philadelphia for one week and subsequent illness from typhoid fever interrupted experiments and what little time I could spare from professional duties latterly has been devoted to writing a specification of a patent to be sent to England. I shall note here now the principal experiments made during the month

1. The success of enlarging the steel armature of the telephone (see page 5) led me to think of dispensing with the membrane altogether.

A disk of thin steel A (Fig 2) about six inches in diameter was fastened in front of the electro-magnet E. On speaking to A the articulation was heard from Z much more distinctly than we had heard before.

Fig 2



2. The following facts have been conclusively proved by our experiments with the form of apparatus shown in Fig 2. Page 5:—

1. That the sounds audible from the Receiving Instrument are loudest when the Speaker condenses the air against membrane by means of his hand.

2. That the sounds from the Receiving Instrument are most distinct when the speaker speaks against the same side of the membrane on which the electro-magnet is placed.

3. That the articulation is most distinct when the membrane is omitted and a simple plate of steel used as in Fig 2. page 15.

4. That the audibility of the sounds depend upon the resistance of the electro-magnets of the transmitting & Receiving Telephones — ~~The greater~~ The greater the resistance of the coils the better the effect — the current being supposed of the same mean intensity throughout.

3. Arrangements have been made with Prof. Rogers for experiments between Exeter Place & Cambridge Observatory — and a line has been erected ~~placing me in communication~~ connecting me with the Boston & Cambridge Circuit at the office of Messrs George & Stearns Electricians No 39 Pearl St.

Conversation was carried on by word of mouth over the circuit between Exeter Place & Pearl St on Friday morning the 10th of November.

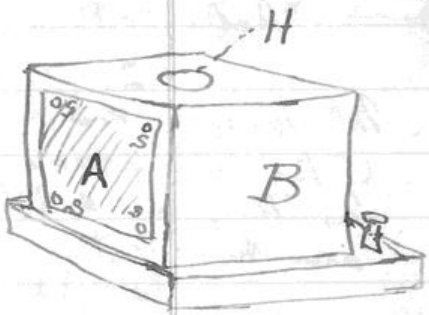
Mr. Greenough and Mr. —— of the Boston Gas works as well as Mr. George were present at the Pearl St End of the line. The instruments used were those shown in Fig 3.

4. Instrument shown in Fig 3 were constructed somewhere about the 19th or 20th of October — before W. Watson left for Philadelphia — and they are still the instrument preferred.

The electro-magnet is placed in a box B of wood. The front of the box was then cut away and a sheet of thin steel A screwed on to it by screws SSSS.

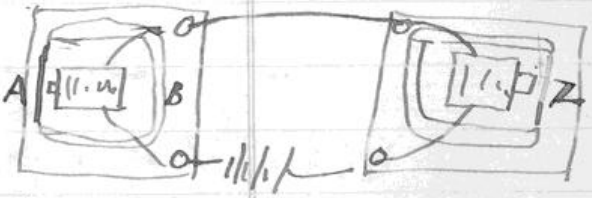
A hole H was left in the top of the box for the purpose of speaking into.

Fig 3



Two instrument were made and arranged upon circuit as in Fig 4. Upon speaking into the hole H Fig 3 the voice was heard very loudly from the other telephone but indistinctly. Upon placing the mouth against the plate A and speaking the sounds became perfectly distinct from the other telephone.

Fig 4



Upon condensing the air against the armature A by means of the hand — the utterance was perfectly distinct & quite as loud as when we spoke into the hole H.

When we blew against A Fig 4 — the sound was audible at Z.

Instrument by Andrew B.

Tuesday Nov. 12th 1876

E. Gilliland

Saturday Nov. 11th 1876

1. Experiment between Exeter Place & Observatory made this evening. Mr. Watson in Boston — A.G.B. and Prof. Rogers in Cambridge. Magnets of 25 ohms resistance produced scarcely any effect, With magnets of 100 ohms resistance sounds came out splendidly. Conversation was carried on with the greatest ease.
Articulation the most distinct yet obtained.

2. Mr. Watson thinks that the sounds were imparted by the armatures of the Morse sounders on the circuit — as they must have vibrated synchronously with the armatures of the telephones.

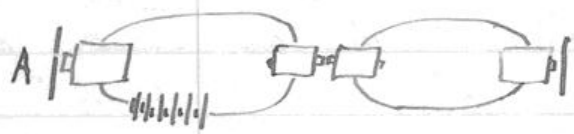
3. Sounds were faintly audible in Cambridge when the battery was cut out altogether.

Notes by A.G.B.
Sunday Nov. 12th 1876

Sunday November 12th 1876

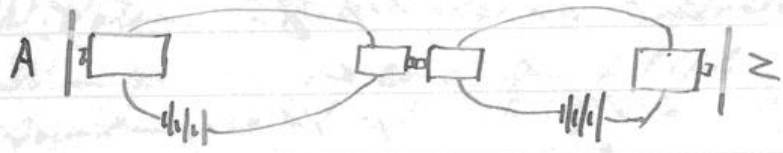
1. Tried following experiment: Sounds uttered in the neighbourhood of A Fig 5 were faintly audible from Z.

Fig 5.



2. The experiment was varied as in Fig 6.

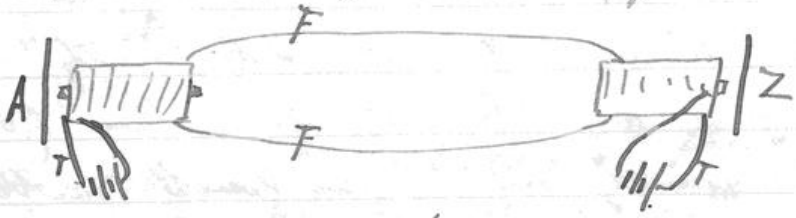
Fig 6



Conversation was carried on between A & Z just as if they had been on the same circuit. The magnets had each a resistance of one ohm.

Thought Fig 7

1.



Use induction coils. Local batteries in circuit with thick wires T — Main circuit without battery connected with fine wires.

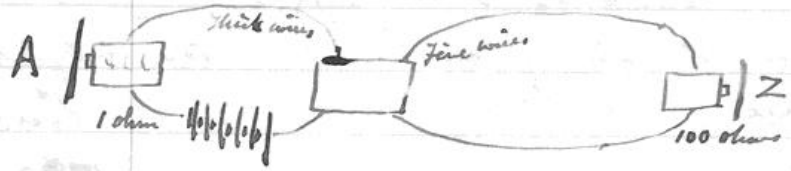
Noted by A. G. B.

Nov. 12th 1876

Monday Nov. 13th 1876

Tried Induction coil as in Fig 8

Fig 8



1. Sounds spoken at A plainly though faintly audible from Z. Mr. Watson thinks that the word "faintly" does not express the intensity audible. He says the sounds were loud although faint as compared with ordinary arrangement.

2. One cell of battery placed on the secondary circuit — fine on primary — Sounds from Z nearly as loud as the same ever had.

3. Three cells on each circuit. Sounds uttered at A audible from Z. Sound uttered at Z audible at A. The sounds heard at A much more distinct than those heard at Z.

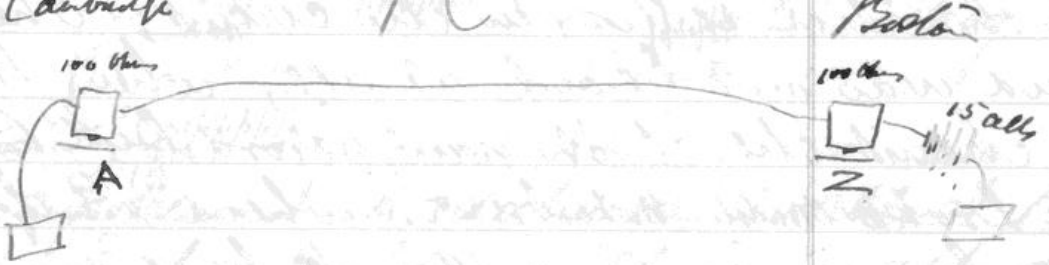
4. Twenty-five ohms coil placed in primary circuit in place of one ohms coil. Sounds much fainter from Z.

Noted by A. G. B.,
Monday Nov. 13th. /76

Monday Nov. 13th 1876

Experiment between Boston & Cambridge this evening.
W. Watson in Cambridge. Battery 15 cells.
Upon placing ear to the Teleph. a loud rushing sound was heard something like the rushing of a tempest through the leaves of a forest. Voice from Cambridge inaudible. Circuit as in Fig 9.

Fig 9



Upon breaking circuit in Boston taps were heard very loudly upon Z. When the circ. was broken at A taps heard softly from Z.

Upon reversing battery rushing sound disappeared. It only came when the zinc element was connected with the ground.

Upon reversing battery W. Watson's voice at A reproduced itself audibly at Z. Conversation was then carried on. Visitors & were present at both ends so there was very little real experimenting done.

At Boston end W. & Mr. Eustis Hubbard.
Cambridge end. Pof. & Mrs. Hayes, W. & Mr. Waldo, Pof. Hill, & Pof. Trowbridge.

Boston Nov. 16th 1876

by A. G. B.

Jr

Tuesday Nov. 14th 1876

We were connected this morning with the Observatory circuit and tested Telephones with Prof. Rogers at the Observ. end and Prof. Bellas the Boston end. the experiment was conducted for the purpose of finding the cause of the rushing sound and the clock beating in the circuit. The rushing sound was not heard at all, when Mr. R. broke the circuit the clock was heard by B ~~B. when~~ ~~B. broke~~ and not by R. when B. broke it was heard by R. and not by B.

The clock is undoubtedly Bonds Clock as we counted the beats and found that they corresponded to Bonds and not to the observatory Clock. Conversation was carried on between the two ends with perfect ease

In the evening Mr. Bell experimented to see if he could produce artificially the rushing sound and found he could exactly by passing the current through a piece of cloth saturated with acidulated water An imperfect contact in the circuit seem also to give the same sound.

The analogy to the wet cloth in the Cam. Circuit is in the cable ~~that~~ crosses Charles River ~~and~~ which Mr. George says is leaky. the experiment leaves little doubt that the rushing sound is caused

by the decomposition of water (see page 25)

Noted by T. A. W. Nov. 15th 1876

Wednesday Nov. 15th 1876

Tried following Arrangement with the induction coil. #1

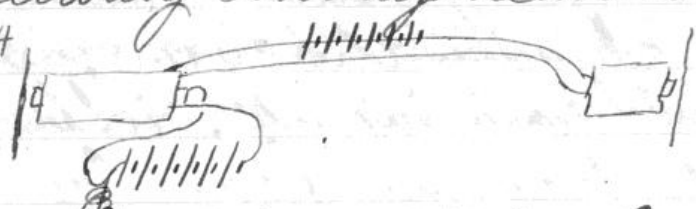


Fig 10

Words spoken at A distinctly audible at B. while making this experiment we used the double stethoscope to listen with, and by resting one edge of it ~~upon~~ against one side of the membrane so as not to deaden the vibration of the centre we found that the sounds were very much more intense and the articulation very much more audible we propose to go to Codman & Shurtleff's and see if we can procure ~~one~~ a rubber cone of ~~this~~ shape.  in fig. 11 large enough to fit over the whole membrane and used both as a speaking tube and a hearing trumpet.

Putting magnet over which spring was being plucked into the primary circuit ~~at~~ at A. the sounds were plainly audible at B. and putting it into the secondary circuit at A. ~~it~~ they were still audible, with neither increase nor decrease if anything a slight decrease. *

* Three cells on primary circuit and three upon secondary circuit. A.G.B.

Tried Gage's Sounding Box as a receiver and transmitter for the voice and got unsatisfactory results

Tried our old receiving instrument the iron Box magnet in circuit with one of our latest forms of Telephone, used it both as a receiver and transmitter and got the best results we have yet obtained we will try to get an arrangement of speaking tube and hearing tube like this.

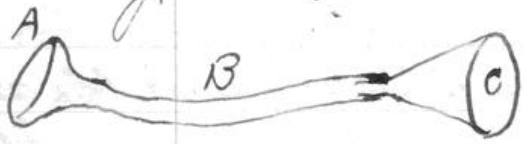


Fig 11

A = Mouth and ear piece
B = Flexible tube
C = Magnet end

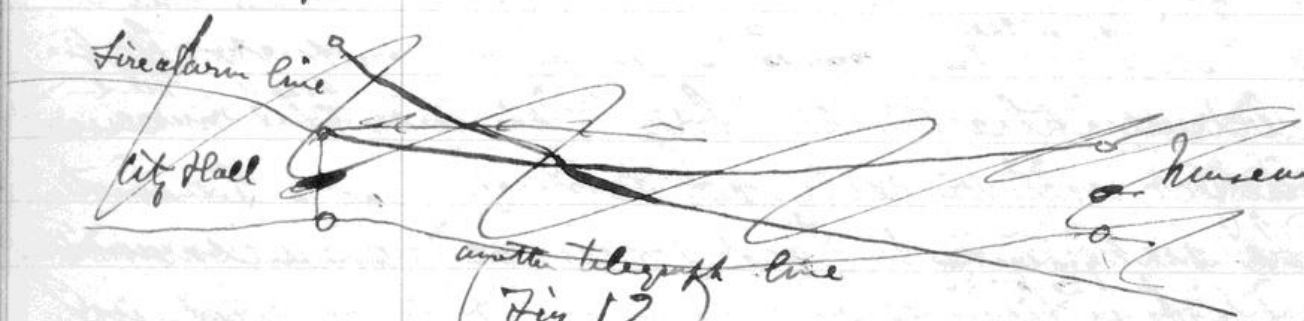
We found this evening that the rushing sound can be produced perfectly by placing the circuit closer of our key lightly against the side of the anvil but could not produce it ~~by no matter how~~ with the Platinum points of the key no matter how lightly they were rested together which would seem to indicate that the varnished brass of the circuit closer had something to do with the production of the sound. Is this an electrical effect analogous to the vibration of Prof. Bars by heat it seems to me that it is a vibration so rapid that it sounds like a hiss

Noted Nov. 15th 1876 D. A. N.

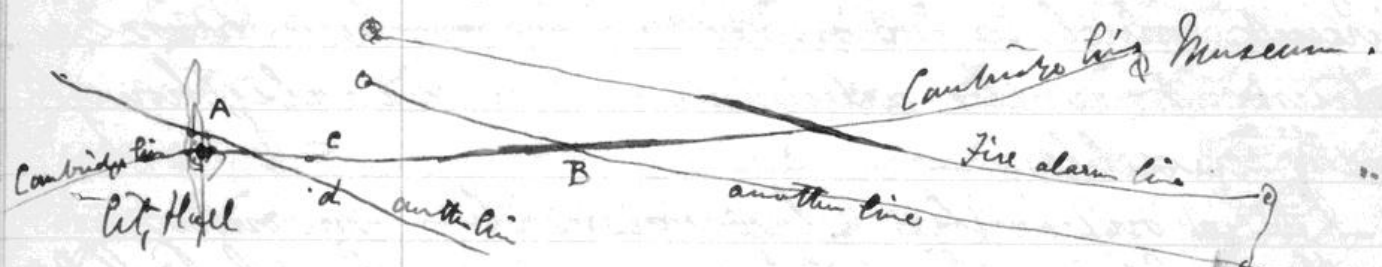
Friday Nov. 17th 1876.

On Wednesday night upon returning from Cambridge I connected my telephone in circuit with Cambridge wire for purpose of observing noises on circuit.

Could hear the clicking of a clock — twenty-eight ticks and then a pause. Also heard faint tapping as if due to operating on another circuit. Occasionally the rushing sound referred to on pages 21 and 24 made its appearance — but only when the Zn pole of the battery was put to earth. I do not understand why the Zn pole plunged to the earth should make any difference if the cause is the decomposition of water as rendered probable by experiment noted in page 24. I am inclined to think now that the cause of the rushing sound was not a defect in the cable from Boston to Cambridgeport as supposed before — but must be located at City Hall. Mr George gave me particulars of the fault discovered there which was evidently of long standing.



(Fig 12)

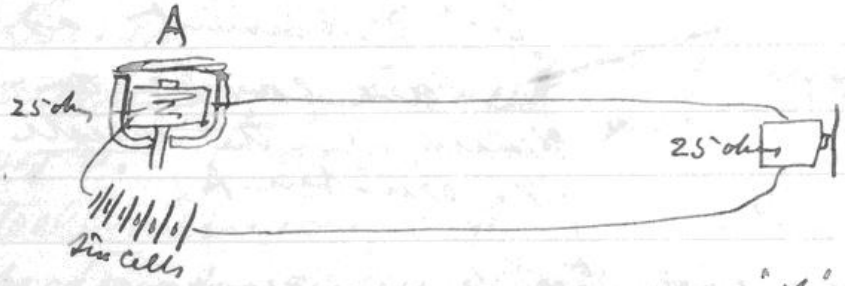


The cambridge line passed between the fire-alarm wire and another wire in passing from City Hall to the Museum — and it had sent downwards so as to touch the lower line at B. In order to remedy this — the Cambridge wire had been tightened so as to clear the lower line and had been fastened to the same insulator A upon which was fixed as the support for another line. The two wires had been fastened

Together with insulated copper wire! Last Monday evening was quite wet and stormy — and the insulating materials had become wet so that probably there was a leak from line C to line D and the decomposition of the rain-water at this point was probably the cause of the rushing sound heard on that evening. This probably would explain the reason for the sound only coming when the ± pole was put to earth — for there must have been a battery on both lines C & D and when these were opposed to one another — they would neutralize each others action at A and thus no ~~sound~~ decomposition of the water takes place and no sound be heard. On Wednesday evening the line C came into contact with line B and stopped communication. The major portion of the current from our battery went to the earth through the line B — and only a small portion of it reached Cambridge by line C. Thus taps ~~in B~~ made in Boston were loud while taps received in Boston from Cambridge were very feeble. ~~(See note in page 24)~~ And yet Mr. Watson's voice was audible in Cambridge and a sentence or two was understood. For instance I heard and understood the sentence — "If you understand what I say send me five taps" —

Yesterday we tried old receiver as a transmitter. as in Fig 13 with great success. The sounds audible

Fig 13



at Z were louder & more distinct than any yet obtained. When Mr. Watson spoke at Z sounds audible from A were loud and distinct.

28

We propose to make Instruments like those shown in Fig 14 and 15.

Fig 14

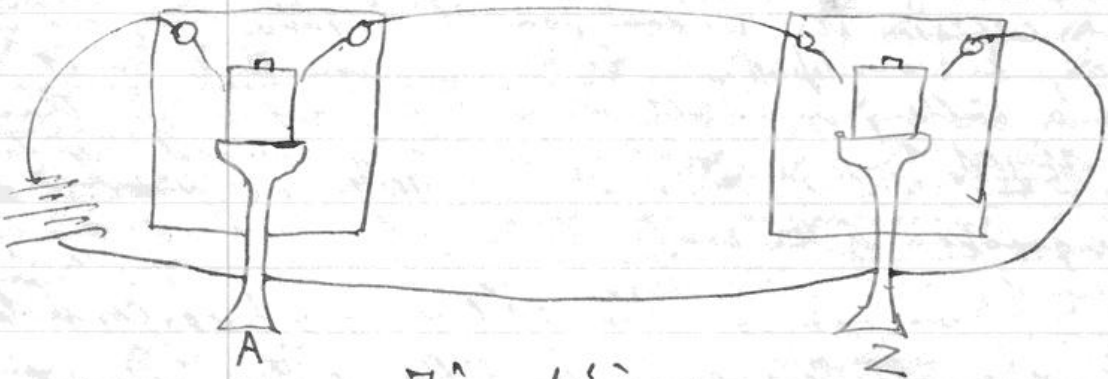
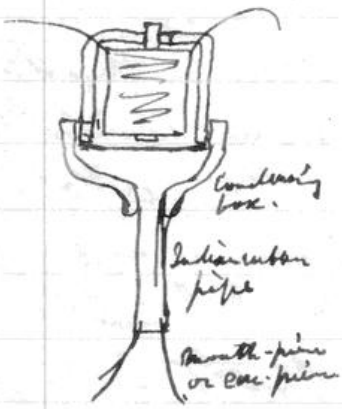
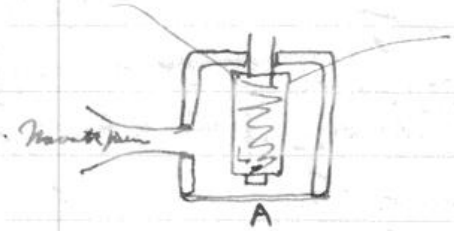


Fig 15



Mr. Watson has constructed apparatus shown in Fig 16 — which we have been unable to try yet. We anticipate

Fig 16

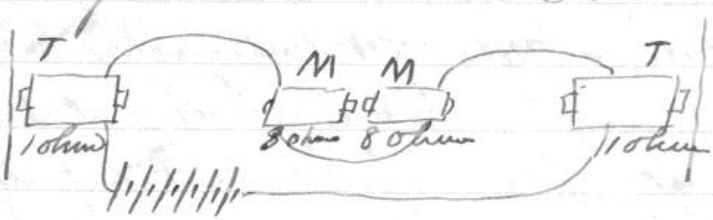


good results from this instrument as the air can be condensed upon the inside of the armature A

Notes by A. G. B.
Nov. 27th 1876

Saturday Nov. 18th 1876

Tried the experiment shown in the following diagram



T-T- Telephones M-M- Single Pole Electro Mags. and moved the Mags. to and fro while a sustained musical note was being sung, could not perceive any difference in the ~~articulation~~ intensity of the sound.

While carrying on conversation in the ordinary manner through the wire I suggested placing a steel disc over the hole in the Box which covers the mag. in the Tel.ph. on doing this the articulation became louder and much more distinct than when we talked into the hole of the box we also found that a piece of paper over the hole produced the same effect but in a somewhat more intense degree a paper collar box inverted over the hole and the voice condensed in to that improved the sound still more. The collar box inverted over the steel membrane gave nearly as loud and more distinct articulation than when we talked directly on to the membrane.

Ever since we first tested our latest form of telephone we have been puzzled by the fact that talking into the hole that was made for that purpose in the box was transmitted very indistinctly though loudly, very different results from what we expected after trying our old form of Tel. by talking at the back of the membrane that is the side on which the magnet is. Our experiments to day, noted above, of placing a membrane over the hole and talking against that instead of directly into the box have led me to form this theory, which I think will explain the indistinctness that we have heretofore been unable to account for.

The theory is this: The air contained in the box has a rate of vibration of its own, and reinforces certain tones more than others, thus distorting the form of the composite vibration; now it seems to me that placing a membrane over the hole would force the air contained in the box to copy more perfectly the form of the vibrations.

This theory if correct will explain, why all forms of speaking tubes, that we have used, to converge sound vibrations upon the membrane have given such poor results.

We propose to try the Phonautograph Cone arranged with a membrane over the large end, and a steel membrane at the small end, then a slight motion of the large membrane will create a large motion of the small membrane

on the principle of the Hydrostatic Paradox, and a small piston working in a pipe might be used instead of the small membrane.

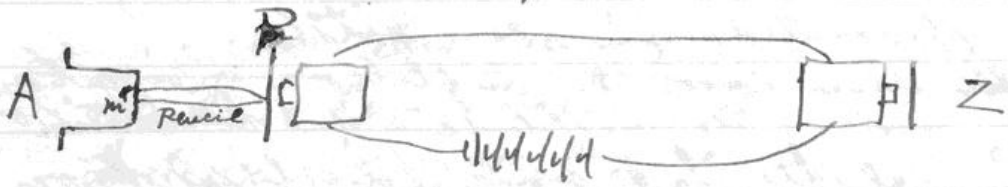
Prof. Bell suggests that the above idea if correct may be applicable to all forms of hearing tubes for deaf persons.

Noted Nov. 18th 1876 T. A. Watson

Saturday Nov. 18th 1876

I am inclined to think that Mr. Watson's idea noted above is very valuable as affording a means of setting the steel disk in vibration without placing the mouth in close contact to it. An experiment made at the same time as those mentioned above has not been noted. A lead pencil was placed

Fig 17



between the plate P and the membrane M of an ordinary "Thread telegraph" A. Upon speaking into A sounds were audible from Z with nearly as good effect as when the voice was condensed directly against P. Upon speaking to Z sounds were clearly audible from A.

Prof. Cross of the Institute of Technology has pointed out a defect in the Modulatory currents produced by the vibration of bodies capable of inductive action. The intensity of the current ~~varies~~ not

only directly proportional to the velocity of the motion of the inducing body, but inversely proportional to the square of the distance of the vibrating body from the pole of the electro-magnet — or $I = \frac{v}{d^2}$.

Hence the form of the sound-vibration is not produced in fac-simile in the electrical current — but is distorted — and it becomes a question whether this distorted vibration is copied in the armature of the receiving telephone or whether the armature of the receiving telephone copies the exact motion of the first. I am inclined to think that this is so — but certain peculiarities in the effects produced seem to me to be explicable upon the idea suggested by Prof. Cross. For instance the fact that we have observed again and again that very low soft sounds are audible more distinctly at the receiving end than louder sounds. Indeed it has often occurred to us that what we gain in loudness we lose in distinctness and vice versa. Again we have observed that articulation in a high pitched voice is much more distinct than when uttered in a low pitch.

~~In both these cases the amplitude of vibration of the plate~~ The amplitude of the vibration of the inducing plate is of course smaller for soft sounds than for loud and, for high pitches than for low — Hence the distance from the pole of the magnet is not varied so much in soft or high tones as in loud or low tones — and the distorting influence of the distance is not so great.

This has led me to think of the effect of vibrating the conducting wire in a liquid of high resistance — but I now see that here also a distorting effect is produced — for as the wire descends into the liquid the current becomes absolutely stronger and stronger — but as the

membrane which carries the wire descends lower and lower its motion becomes slower & slower until it stops. Now if the current were purely undulatory its intensity would diminish as the motion of the wire diminished and when it reached its lowest point it would be zero — but the fact is that at the lowest point the current reaches its maximum and hence the vibration must be very greatly distorted — probably still more distorted than in the case of the induced undulatory current.

I think then that in seeking to increase the audible effects — we must not do so by increasing the amplitude of vibration of the inducing body but by increasing the resistance of our magnets & the strength of our battery. Indeed I think that with our present arrangement our effort should be to produce the maximum of inductive action with the minimum of vibratory motion in the plate.

This evening we tried apparatus between Boston & Cambridge. The circuit has been put in good order this morning. W. Watson was in Boston — I in Cambridge.

I reached Cambridge about 7.40 and at that time W. Watson should have been ready to begin experiments. Upon connecting my telephone — I could hear nothing — nor could I obtain any trace of a current. Upon making & breaking the circuit no sound was audible. I waited till eight o'clock occasionally tapping — but with no effect. I then examined all the connections at the Cambridge end and found them perfect. ~~At half past~~ About ten minutes past eight I found that ~~he~~ a feeble

current had suddenly made its appearance and that Mr. Watson was tapping. We had the 100 ohm coils on our telephones. Upon listening I could hear Mr. Watson's voice very faintly — only a word sentence or two intelligible. I then signalled him by the tap-alphabet to change the coil & put on the 250 ohm coil.

This was done & the articulations all over became louder and more intelligible but it was not nearly so good as with the 100 ohm coils on Sat. Nov. 11th — see page 18.

Mr. Watson informed me that the battery was turned on about a quarter before eight — but that he could not obtain any results. At ten minutes past eight he reversed the battery and then there was a slight manifestation of a current. As we talked the sounds seemed gradually to become louder and more distinct — until they were fully as loud as on Sat. Nov. 11th. Mr. Watson informed me that Mr. Gustis Hubbard was present with a friend "Mr. Bash — B-u-s-h- Bash". I held conversation with them through the wire — and then Mr. Winlock spoke with Mr. Hubbard at the Boston end.

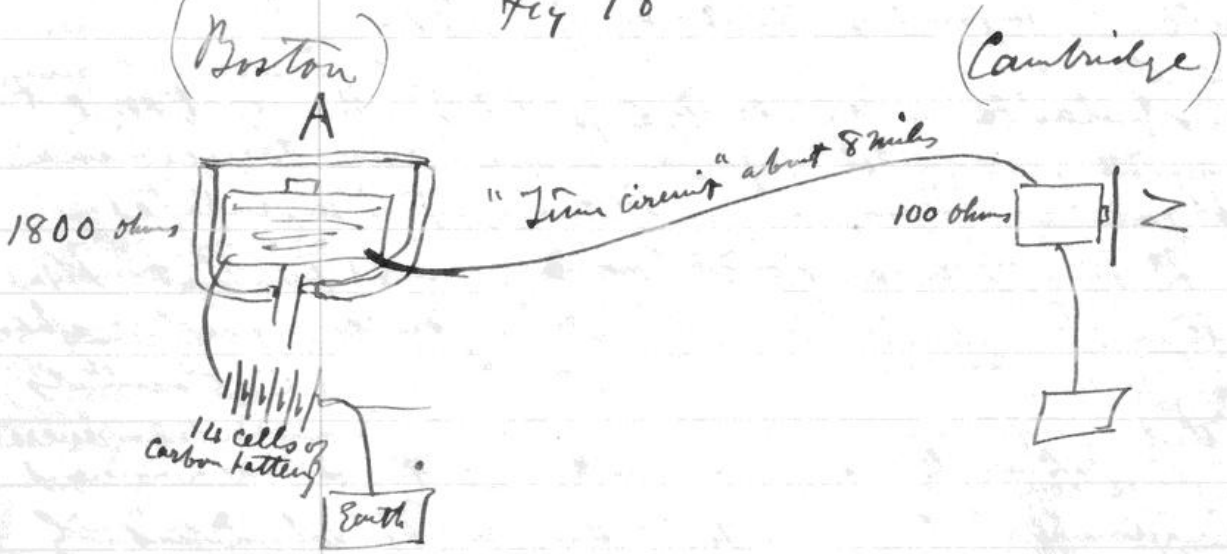
After some conversation experiments were resumed. The five hundred ohm coils were put on. The sounds obtained were very faint — as faint as with the 100 ohms.

The 100 coil was then replaced at my end, but by a misunderstanding Mr. Watson had in his instrument the 250 ohm coil. Nevertheless the articulation was audible at either end as loudly as we have heard it yet. W. Watson then changed his coil for the 100 ohm coil originally employed and the sounds at either end were as loud as we heard them. The arrangement was precisely similar as at first when we were unable to hold communication. It seems to me that the iron cores of the magnets must have

permanent
acquired a certain amount of magnetism and that
the reversal of the battery at first had opposed
tended to reverse the magnetism and hence we had
obtained no effect — When the battery was again reversed
the magnetism of the cores had been almost destroyed
or reversed — so that at first we obtained feeble
results — but little by little they recovered their power
and at last. Mr Watson then agreed with me as to
the principle but thought that the effect was
more likely due to the magnetism of the steel
plate. The cores were of the best soft iron
and the reversal of the current would instantly reverse
their polarity — but the plates were of steel
and they would require some time to become
fully magnetized — or to be de-magnetized.
In this I agree with him. To test the
matter I reversed the direction of the current
through my magnet and at once the sounds
emitted by it were much feeble. Upon re-reversing
the direction of the current the sounds recovered
their power.
In order more conclusively
to settle this point I directed Mr Watson to reverse
his battery for five minutes — and after experimenting
to replace it as it was.
When the Battery was reversed we found it
impossible to communicate by word of mouth —
even the sounds made by making and breaking the
circuit were very feeble. When the battery was
again reversed so as to leave it as before — the
sounds audible were exceedingly faint — but each
succeeding sentence came out louder
and louder until in about five minutes they

heard the note due to its vibration distinctly.
He then removed the telephone and vibrated the tuning-fork in undulatory contact with the circuit — heard the sound distinctly.
I also heard it but much more feebly when plain water was used.
The following experiment was then tried as illustrated in Fig 18.

Fig 18



I heard at Z distinctly but faintly what W. Watson said at A — but still more extraordinary is it that W. Watson at A heard distinctly but softly what I said at Z.
That is — the undulations induced in a magnet of 100 ohms had traversed 8 miles of wire and a coil of 1800 resistance and produced an audible effect at the distant end of the circuit. This seems to me to be very encouraging.
We have decidedly made a great step in advance to-day by understanding the causes of many of our difficulties. The experiments with coils

of different resistances must all be repeated
as the results obtained to-day are unreliable from the
fact that we were not careful to pass
the current always through the coils in the
same direction.

Noted by A. G. B.
Sunday Nov. 19th 1876

Sunday November 19th 1876

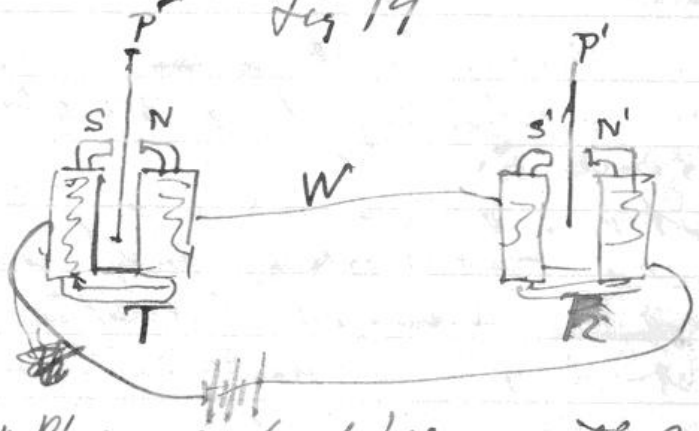
It has struck me to-day that the instrument
invented on the 11th of July gets over every difficulty
yet observed in utilizing the undulatory
current — & will doubtless prove sufficiently powerful
to be used without a battery. So many ideas
noted in my note-books have not been tested that
I think it may be valuable to collect them together.
I must certainly have the Instrument shown on
page 30 (Vol. 2) Figs 4, 5, & 6 — constructed.

Mr Watson suggests writing all experiments "to be
tried" in a separate book or in another part of
this book that they may not be forgotten. I
think it may be well to make a separate note
of such experiments — referring to page and illustrations —
but it seems to me that the experiments to be
tried should be described in the same part of
the book as experiments already tried and under
the dates of their conception — so that the continuity
of the researches may not be interrupted — for one
experiment suggests another and if the two things
are noted in different places the continuity is lost.

I shall read through all the books
of Experiments, and keep a record in another book which need

not be preserved) of the pages for where proposed experiments are described. As fast as we try these experiments — we can strike them off in our book as tried. The apparatus shown in Figs 4, 5, & 6, (page 30 Vol II) certainly seems to me from theoretical considerations more perfect than any others yet described.

Fig 19



The plates P & P' are rendered permanently magnetic in the way shown in detail in Figs 4, 5, & 6 page 30 Vol. II.

Now the vibration of P creates in ~~each~~ the coils of ~~pole~~ electro-magnet N, an undulatory current which is distorted ~~by the effect of varying distance~~. in each coil by the superadded effect due to the varying distance of the plate. ~~But when the line — one N~~

But the effect due to the varying distance of the plate from the poles is just neutralized by the opposite effects produced in the two coils; while the effect due to the mere motion of the plate is doubled.

For instance let the plate move towards N.

~~In the coil the impulse produced by the~~

The approximation of P & N and the separation of P & S produce currents of the same polarity in the coils of N & S because the poles S & N are of opposite polarity — hence the effect due to the mere motion of P is the same in both coils & is therefore doubled, — but the distorting influences of the distance of the plate is done away with of

coils of S & N have equal resistance. For the current in N will be that caused by the motion of P, ~~plus the disturbing influence due to variations in the distance of the plate from~~ (increased by the approximation of P & N — while in Coil S the current will be that caused by the motion of P diminished by the separation of P & S.

Hence if P ~~was~~ rests normally midway between S and N, and if the coils of S & N have equal resistance the increase of the current in the one coil just balances the diminution of the current in the other — ~~thus leaving~~ and leaving the undulatory current undistorted but of twice the intensity it would have had if the electro-magnet had been on only one side of the plate P.

I think that the reason this form of apparatus has not been ~~tried before~~ made owns the difficulty in communicating a correct vibration to a plate like P without placing the mouth closely against it.

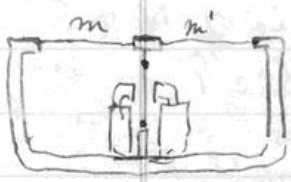
We Watson's plan (see Page 30) or ~~the~~ some plan founded on experiment illustrated in Fig 17 page 31 may however be made of use. If my theory is right it should be found that upon speaking loudly to plate P, Fig 19 the distinctness of the articulation heard at P' should be undiminished.

~~First form of test~~

I propose to have instrument made so as to enclose in boxes of different kinds, to test the best way of setting the plate in vibration.

Fig 20

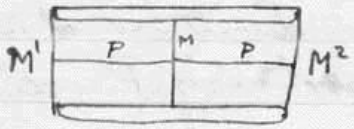
Fig 20 illustrates one proposed form of box in which m, m' are membranes.



Another form is shown in Fig 21 — in which

M represents the ~~plate~~ steel membrane, P a pencil or other ~~conductor~~ solid conductor of sound, and M' M² — stiff membranes attached to P.

Fig 21



W. Watson agrees me with me in thinking this plan ~~is~~ feasible.

Noted by A. G. B.
Nov. 19th 1876

P. S. The instruments shown in Fig 19 should work with or without a battery — and the direction of the voltaic current should be immaterial.

Monday Nov. 20th 1876

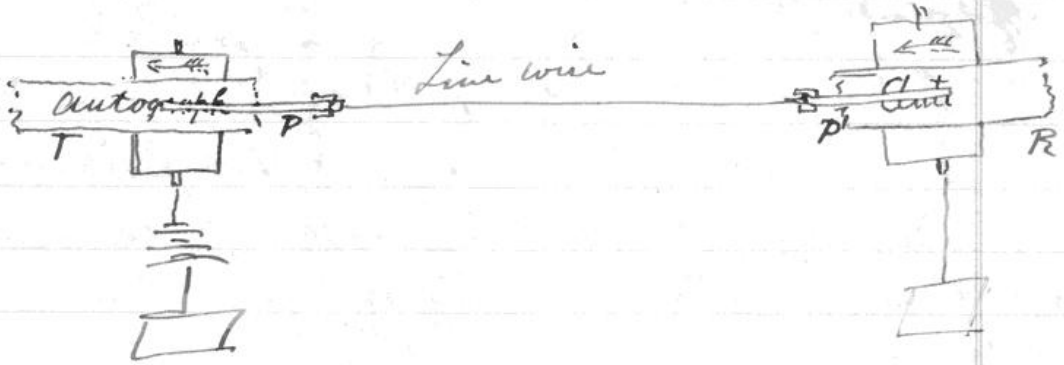
W. Watson has been at work to-day constructing apparatus shown in Fig 19th. He expects to have it completed tomorrow about noon.

Noted Nov. 21st 1876
by A. G. B.

Tuesday Dec. 21st. 1876

A new form of Autographic Telegraph has just occurred to me. Vibrating plates tuned to the same pitch at either end of the line ~~would form~~ can be used and styles attached to them as in Phonautographic experiments.

Fig 22



Write message on metallic surface with non-metallic ink at T — receive it on chemically prepared paper at R. The plates P P' may be kept vibrating by means of local batteries or by wind or by other means.

All that is necessary is that they should be tuned to unison with one another. Such a message could not be intercepted unless by an instrument of whose armature is of similar pitch.

It may be possible that autographic despatches might be transmitted simultaneously by using plates of different pitch for each message as in Fig 23.

The messages of T + T' would of course ~~be copied at both R + R~~ both be received upon each of the Receivers R + R' — but the message of T' would come out as an irregular line upon R and hence would not be legible there — producing an effect somewhat like

that shown in Fig 24 — and the message of T would produce a similar illegible effect upon the R' as in Fig 25.

Fig 23

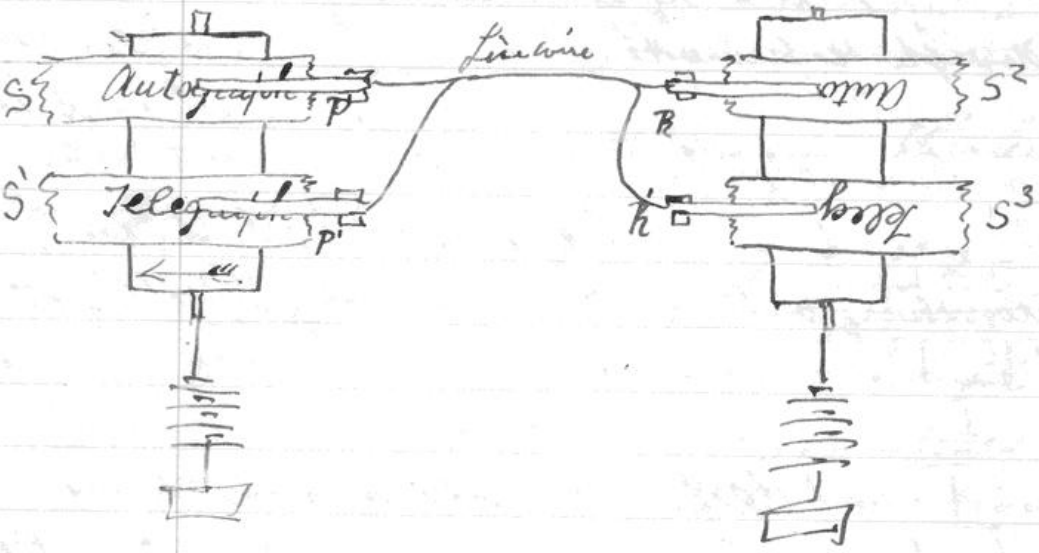


Fig 24

Fig 25

Autographs

Message as received at R

Telegraphs

Message as received at R'

Many months ago I had the idea of using vibrating bodies — as a means of regulating the speed of mechanism so as to produce synchronous motion in two machines at distant places.

It seems to me that the above plan is feasible and we must certainly try it after we have perfected the transmission of utterance. The vibration of the plates P & P' R & R' should be sufficiently rapid and the motion of the slips S S' S² S³ sufficiently slow to prevent the motion of R & R' being drawn as a curve upon S² S³.

Notes by A. G. B.

Jan. 21st 1876

Wednesday Nov. 22d 1876

Completed instrument shown on P. 38 Vol. II and tested in all the ways we could suggest with very poor results, but Mr. Bell thinks that we are not treating it fairly for we cannot hear the ~~vibrat~~ articulation ~~nearly~~ when we use only one pole of the El. Mag., nearly as well as with our Box telephones.

We find that the L shaped Perm. Mag. will not magnetize the Membrane attached to it. and propose substituting an Elec. Mag. for it

Noted Nov. 23d 1876 By
T. A. Watson

Thursday Nov. 23d 1876

Constructed to day Membranes, to fit our Box Tels, of iron rather thicker that the steel we have been using. have turned an annular recess in one pair, making it much thinner near the centre.

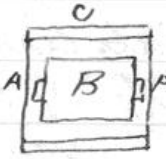
I have also enlarged the hole in the top of the box, making it nearly 4 inches in diam. instead of 1½ inches.

Several ideas in regard to the Instr. have occured to me to day which I have noted under the head of "Experiments to try" in the last part of the book, but Mr. Bell thinks I had better repeat them here.

The ideas referred to are these

1st " The Membrane of the receiving instrument must be more delicate than that of the Trans. Inst. as the force acting upon it is far more delicate than that acting upon the trans. Membrane.

2d " Rec. Inst. made thus.



A-A = Membranes of Iron or Steel

B = Mag.

C = Box enclosing the whole

would I think neutralize the distorting effect suggested by Prof. Cross. if such effect really exist- ed give the sounds of ~~more dist~~ greater intensity than with our present form.

3rd " In our present form of Inst. we get the inductive effect ~~only~~ of the centre of the membrane now if we were to make the face of the core of our Elec. M. as nearly as large the membrane I think we would utilize the inductive effect of the whole of the vibrating membrane

Noted Thursday noon Nov. 23d " 1876

Thursday Nov. 23d 1876

I disagree with some of Mr Watson's conclusions - for instance - the first

Thoughts resumed November 25th 1878
at the Massachusetts General Hospital

Letters appear every day in the newspapers about the application of electro-magnetism as a motive power and I think it would be well to complete an electro-motor on my old principle — and patent it before any one else thinks of the applicability of the Telephone as a means of obtaining a motive power from electricity. The extreme delicacy of the Telephone as a means of detecting the presence of a very feeble current — (equalling if not exceeding the delicacy of a reflecting galvanometer) — is a proof to my mind that by means of the Telephone we obtain from an electric current a very much larger proportion of mechanical power (~~in the shape of mechanical vibration~~) than by any other contrivance we possess at the present time. The sound audible from the Telephone is the audible index of the mechanical motion of the plate — unless indeed it should be proved that the sound is simply produced by a molecular derangement in the plate. In a Receiving Telephone it is undoubtedly the case that there is a mechanical movement of the plate as we can feel it tremble ~~under the influence~~ when producing a loud sound — but on the other hand the sounds are emitted by large masses of iron when ~~subjected to the attraction of~~ used as Telephone armatures.

It is almost inconceivable that the articulate sounds produced for instance from a hammer-head in place of a plate of iron can be due to a mechanical motion of the whole hammer-head and I am forced to the conclusion that in every case (in the Receiving Telephone) we have a double action produced — a mechanical movement and a molecular vibration. These two motions are produced simultaneously but in different proportions according to the mass and shape of the armature.

It is probable that as we increase the mass without changing the surface exposed to the magnet — we obtain molecular motion at the expense of the mechanical motion and vice versa — and when our armature is very thick and massive as in the case of the hammer-head — the sound audible may be considered as due entirely to molecular movement. In a thin plate however it seems to me likely that the sound is produced chiefly if not entirely by the mechanical action of the plate — and I would utilize a thin plate as a means of obtaining power from electricity.

Magnets exert great power upon their armatures when these latter are placed very near to the poles — but the power decreases so rapidly when the distance between the armature & the poles is increased — that the problem in utilizing the attractive power of the magnet is to produce a long stroke by a very

slight movement of the armature. This can be accomplished and has been accomplished - by ~~[illegible]~~ making the armature the short arm of a lever and using the long arm to actuate mechanism but here it is evident that increase of stroke is obtained at the expense of power so that some combination of magnets is wanted to give the needed power - and not only do the magnets always act at a mechanical disadvantage - but the complication of mechanism and the friction of the different parts - must very much reduce the power before it can be utilized in producing work.

Now the plan I explained to my father in the summer of 1874 and to Mr Watson and to Mr Hubbard in the winter of 1876-5. of combining the power of a number of magnets through the medium of an incompressible fluid such as water seems to me eminently feasible - especially if the armatures of the magnets are thin plates as in the Telephone. ~~and to communicate their motion~~ The power of any number of magnets may be combined in this way without loss due to mechanical complication or to friction and can be utilized so as to produce great motion and little power - or great power and little motion - as desired - by ~~[illegible]~~ causing the water to actuate a piston of greater or less ~~[illegible]~~ diameter.

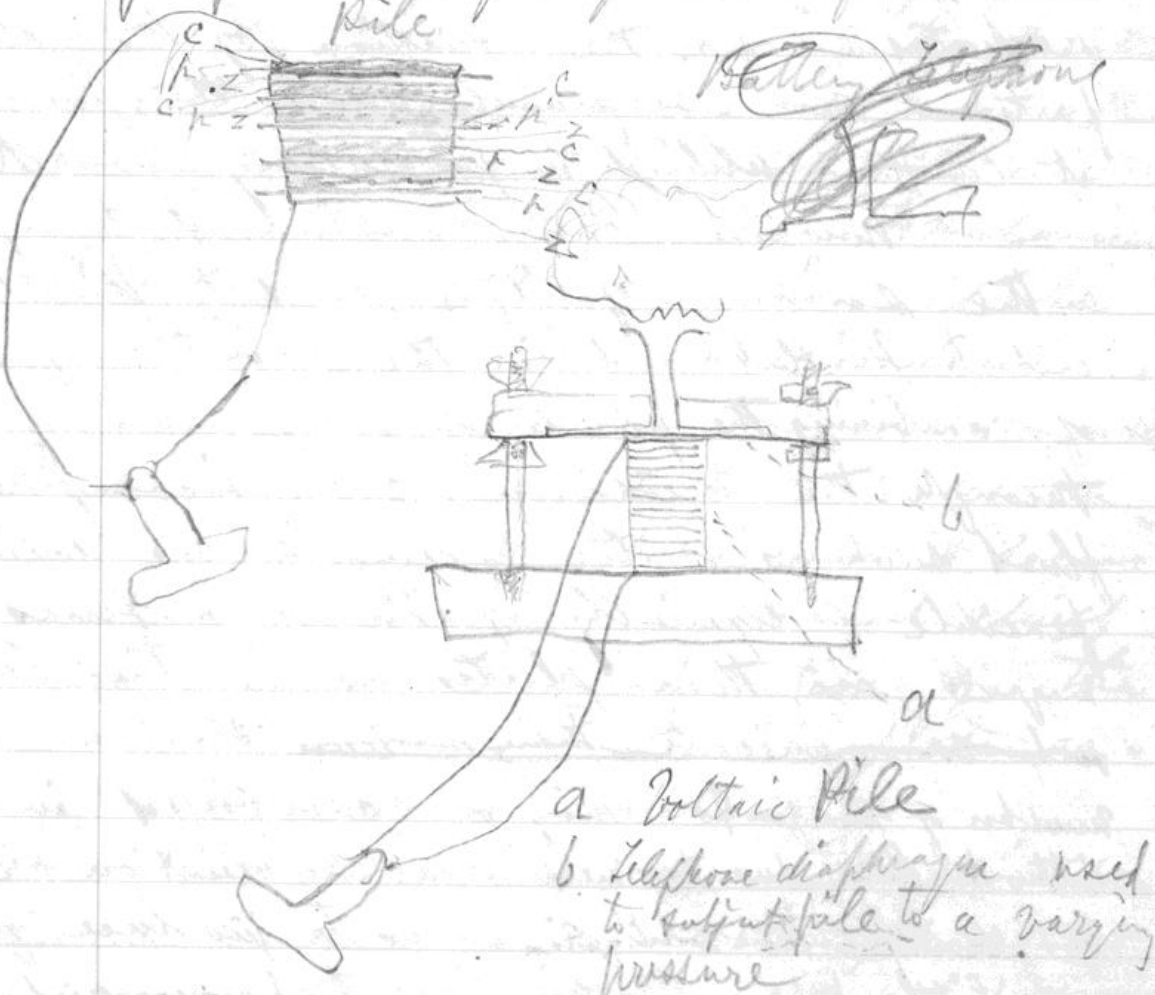
(See new Note-Book) Noted Nov. 25th. 1878
G AGB

Mass. Gen. Hospl. Dec. 2d 1878

My new note-book is in Cambridge - so I jot down here a few ideas for trials.

~~Simplest way in which~~

Make the original voltaic pile. Take discs of copper & zinc ~~&~~ separated by moistened cloth - calico - cotton - paper or some suitable substance, and subject pile to vibration by means of Telephone diaphragm - as follows:

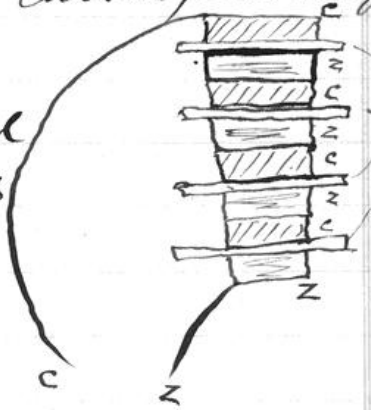


a Voltaic Pile

b Telephone diaphragm used to subject pile to a varying pressure

Instead of copper carbon might be employed and then we would have a double action. Internal resistance of battery would be diminished by the approximation of C carbon and zinc poles separated by the moistened cotton and also by the pressure of the carbon & zinc surfaces in contact (à la microphone) — Vibratory action imparted to the battery would probably cause a very much greater variation in current than simply varying the external resistance.

Carbon pile exaggerated to make clear its construction



The experiment can be very easily tried and if successful we can then seek to construct a vibratory battery that will be constant in its action and not be liable to polarization.

If successful I see no reason why the loudness of the articulation might not be increased almost indefinitely by increasing the number of elements in the pile — and by using induction coil

Pass current from battery through primary wire of coil — and have telephone in circuit with Secondary coil. If the variation of current could be made so great as to produce spark upon Secondary coil — we would have the varying pitch of the voice produced by the spark — and it is just possible that even articulation might be produced by it — It would indeed be a novel thing to hear articulation by the spark of an induction coil without the use of any receiving telephone. Feby 22nd 1876

Experiments to try

Do the Magnets with armatures in circuit with the ~~the~~ telephones strengthen the modulatory effect

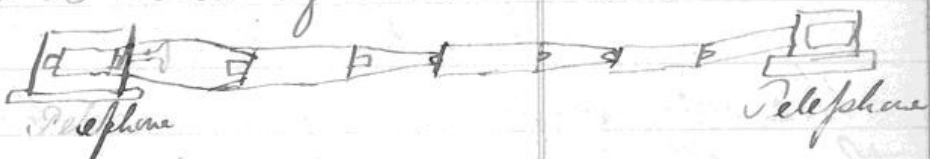
Try 2 persons talking at once

Verify the ~~extra~~ results obtained by using ordinary Morse Sounders for Telephones

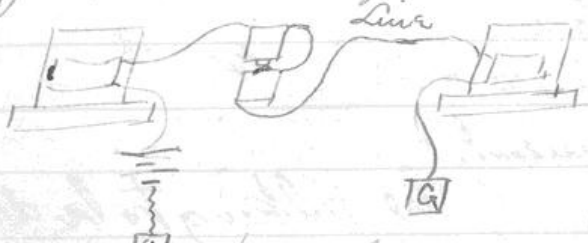
Settle whether the box on the back of our latest telephones has anything to do with the improvement that these instruments show on the former instruments.

Try large box on the backs of our large Membranes

Try the effect of a series of induction coils arranged thus



Try this arrangement



try multiplying the Magnets in the above arrangement

2

Prof. Hill suggests holding the bars in the teeth to see if we can hear the articulation ~~at~~ any better

Nov. 18th 1876

All of our old experiments having for an object the transmission of the voice have had one element of failure in them. viz. the armature or wire to be vibrated ~~being~~ was attached to the central point of a flexible membrane ~~it~~ which point being weighted became a nodal point. repeat all experiments with a stiff disc instead of a flexible one

Nov. 18th 1876

Try Iron instead of steel for our membrane and see if reversing the battery affects the sounds. also try several plates of taggers iron together

Nov. 18th 1876

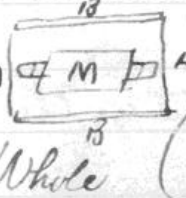
Try a listening with the stethoscope and ~~Hearing~~ Ear trumpet with a membrane ~~stretched~~ over the large end.

Thursday Nov. 23d 1876

the receiving Membrane must be more delicate than the transmitting ~~Do.~~ because the force acting ~~up~~ on it is far more delicate than that acting on the transmitting membrane

Nov. 23d 1876

Try this form of instrument.



M = Magnet
A = Steel Membranes
B. Box surrounding the Whole

(the talking to be done at one end. this form would do I think neutralize the

distorting effect suggested by Prof. Cross and if such effect really is the trouble with our single membrane tests. at any rate I think it will increase the loudness of the articulation

Nov. 22d 1876

Try extending the surface of the 1st pole of the electro Mag. thus A B

A. Membrane

B. Mag. with large Pole

I think that with a magnet like that shown above, more of the surface of the membrane would be utilized, than when the magnet was simply opposite the centre

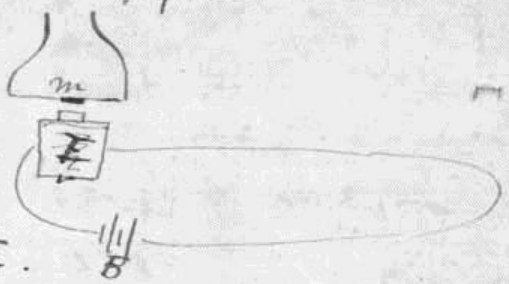
Entered by T. A. Watson Nov. 23/76.

Oct. 1st 1776.

Calculation to determine effect of resist. of magnet in affecting the amplitude of the electrical undulations and audibility of sound at receiving end.

The vibration of m affects the current passing through E and the effect is probably proportional to the resistance of E. Let us consider then the vibration of m as increasing or diminishing the resistance of E. The intensity of the current traversing the circuit BCEB is caused to vary on account of the varying resistance of E.

Fig I



Call Normal resistance of E = z
Resistance of rest of circuit = R
Electro-motive force = E
Effect of motion of m towards E (Fig I) supposed to be proportional to resistance of E call = $\frac{z}{x}$
Effect of motion of m from E (Fig I) call = $-\frac{z}{x}$
Maximum of intensity of current = I
Minimum of intensity of current = i.

$$i = \frac{E}{R + z + \frac{z}{x}} \qquad I = \frac{E}{R + z - \frac{z}{x}} \qquad \text{Hence } \frac{i}{I} = \frac{x(R+z)-z}{x(R+z)+z}$$

There are evidently three cases to be considered viz (1) when $R = z$ and (2) when R is greater or (3) less than z.

Let (1) $R = z$ (2) $R = 2z$ (3) $R = \frac{1}{2}z$

Then 1. $\frac{i}{I} = \frac{10(2z)-z}{10(2z)+z} = \frac{19}{21} = 0.905$

2. $\frac{i}{I} = \frac{29}{31} = 0.935$

3. $\frac{i}{I} = \frac{5}{7} = 0.714$

The amplitude of the electrical undulations is equivalent to the difference between the maximum & minimum intensity of the current $= I - i$

1. Let $R = z$ $\therefore \frac{i}{I} = \frac{x(2z)-z}{x(2z)+z} = \frac{2x-1}{2x+1}$

2. Let $R = z + y$ $\therefore \frac{i}{I} = \frac{x(yz+z)-z}{x(yz+z)+z} = \frac{x(y+1)-1}{x(y+1)+1}$

where x & y are both functions of z, x expressing the change in the resist. of z occasioned by the vibration — & y showing the relation subsisting between the resist. of z & the rest of the circuit R.